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ABSTRACT

The Collaboratory Notebook, developed as part of the Learning Through Collaborative Visualization Project (CoVis), is a networked, multimedia knowledge-building environment which has been designed to help students, teachers and scientists share inquiry over the boundaries of time and space. CoVis is an attempt to change the way that science is taught and learned in high schools through the use of high-performance computing and communications technologies for classroom research projects. Project-enhanced science learning represents a transition from traditional textbook- and lecture-oriented classrooms to ones in which learning occurs in the course of more authentic scientific inquiry. The Collaboratory Notebook extends the metaphor of a scientists' laboratory notebook with facilities for sharing inquiry among multiple project partners who may be distributed across institutions, or across the country. The structure of the Collaboratory Notebook's database is built upon a library metaphor, with a bookshelf, notebooks, and pages being the primary interface elements. When a user logs on, his bookshelf displays all of the notebooks which he is permitted to read and write in. Pages are organized using hypermedia links that describe the relationship they bear to one another in a vocabulary of scientific dialogue. The current design has met with mixed success. On the whole, teachers have been hesitant to assign work to which they cannot confidently attach a grade value and students have been opposed to doing such work; since the teachers are just beginning to adopt the kinds of metrics that will help them to assess the work done by their students' using the Collaboratory Notebook, their efforts to make better use of the tool are likely to more in step with this initiative. (Contains 19 references.) (Author/AEF)

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The Collaboratory Notebook: a Networked Knowledge-Building Environment for Project Learning

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Abstract: The Collaboratory Notebook is a networked, multimedia knowledge-building environment which has been designed to help students, teachers and scientists share inquiry over the boundaries of time and space. Developed as part of the Learning Through Collaborative Visualization Project (CoVis), the Collaboratory Notebook extends the metaphor of a scientists' laboratory notebook with facilities for sharing inquiry among multiple project partners who may be distributed across institutions, or across the country. Within these facilities, the software provides a supporting structure for scientific dialogue which is tailored to students' attempts to learn about science through project-enhanced science learning.

1.0 The CoVis Project

Science, as it is frequently taught in high school, can be a pretty dull affair. After studying several years of it in the traditional mode, a student may come safely away with barely any impression of what a multifaceted and socially dynamic enterprise it can be.

The Learning Through Collaborative Visualization Project (CoVis) is an attempt to change the way that science is taught and learned in high schools through the use of high-performance computing and communications technologies (Pea and Gomez, 1992; Pea, 1993). In this NSF-sponsored testbed project, our team has adapted technologies used by scientists in the research world for use by high school students in their own classroom research projects. Project-enhanced science learning (Ruopp, Gal et al. 1993) represents a transition from traditional textbook- and lecture-oriented classrooms to ones in which learning occurs in the course of more authentic scientific inquiry. This new mode of learning may help science education to overcome the criticism that it helps develop only inert knowledge that students are unable to apply in appropriate contexts (Brown, Collins, & Duguid, 1989; Hawkins and Pea, 1987; Lave, 1990; Lave & Wenger, 1991).

To support the transition to more authentic project-enhanced learning, the CoVis software suite provides "front ends" to visualization tools used by researchers in the atmospheric sciences which make them usable by 9th to 12th grade students of earth and environmental science (Fishman and D'Amico, 1994; Gordin, Polman and Pea, in press). Also, in order to be faithful to the collaborative fashion in which science is often practiced (Lederberg & Uncapher, 1989), CoVis has provided earth and environmental science students at our two participating high school sites with a variety of means to discuss the research they perform with one another, and with distant researchers and science educators.[1]

[1] CoVis is the first educational application of primary rate ISDN service. Using this new service, local ethernet networks at our two participating high schools are linked to Northwestern University's campus backbone and the Internet. Students and teachers participating in CoVis classes each have personal e-mail accounts which they can use to contact scientists worldwide, and full use of Internet "surfing" tools such as TurboGopher and Mosaic to perform research. Also, to support collaboration between the distant sites, students and teachers make use of the Cruiser™ video and audio teleconferencing system developed at Bellcore, and Timbuktu Pro™ screen-sharing software from Farallon Computing. These two technologies, in concert, allow students to share their project work synchronously across classrooms, and with CoVis graduate students at Northwestern.

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One unique tool that we have provided to CoVis students and teachers in this regard is the Collaboratory Notebook. This custom-crafted groupware application is designed to support collaboration on projects across a widely-distributed community of students, teachers and scientists. Sites encompassed by the CoVis community currently include two suburban Chicago high schools, an atmospheric science research lab at the University of Illinois at Urbana-Champaign, and the Exploratorium science museum in San Francisco, California. However, the design of the Collaboratory Notebook permits us to easily extend our community to any locations that the Internet can reach.[2]

Using advanced network technology, we aim to fashion a knowledge-building community that brings isolated classrooms and university labs together in research. In this way, we are attempting to foster a culture in which learning goals and learning resources may be imported and exported freely through classroom walls, creating a "contagion of mind with mind" (Dewey, 1899). We see this as the ultimate extension of the ideal represented by what Perkins (1993) calls a "culture of thinking". By participating in such a culture, students may be involved in ways of working and learning that are currently restricted to university research labs, and may consider scientific careers more seriously than they otherwise would. In any event, their impressions of what "doing science" is like may be more substantial than the rough caricatures that many students depart high school with.

This paper describes the place that the Collaboratory Notebook has within this vision. We begin by outlining some of the design rationale that have driven the initial development of the software, including assumptions made by the researchers about the classrooms in which it would be used and the way that project-enhanced science learning and teaching would be practiced there. We then attempt to lay out the lessons that we have learned during the early days of the software's use by students, teachers and scientists, and discuss more broadly the implications of these lessons for the development and use of groupware for school settings.

2.0 A Brief Introduction to the Collaboratory Notebook

Most simply, the Collaboratory Notebook is a structured hypermedia database in which students and other CoVis community members can record and elaborate upon project ideas and efforts. These recordings take the form of text and annotated images such as charts, graphs, satellite photos and other scientific visualizations that are generated in the course of a project.

The organizing structure of the Collaboratory Notebook's database is built upon a library metaphor; with a bookshelf, notebooks, and pages being the primary interface elements. When a student, teacher or scientist logs on, his bookshelf displays all of the notebooks which he is permitted to read and write in.

Bookshelf
Notebooks available to:
afranz, destrow
Global Warming • igeno
Groundhog Day • afranz, jharper, krange
Heating,Ventalation,A/C (HVAC) •
Hurricane Project • ufranco, jballard
hurricanes • ddrins
hurricanes and weather • dlegg, corr
lake effects • dostrow, jcairmy
materials & water systems • rchristophe
Mrs. Hoffman's proposal • nbabouj, rall
Low weather prediction • flenno, dousti
Open Notebook

Figure 1. A Bookshelf. The color and letter on the icons at left indicate whether the notebook is a private journal (J), group project notebook (P) or public discussion (D).

[2] The Collaboratory Notebook is a Macintosh application which runs on 7 Quadra 700s at each of our participating high schools. This application functions as a client to an Oracle database maintained at Northwestern University on a Sun Sparcstation, which stores all notebook data. Communication between each Macintosh and the database server takes place via TCP/IP using Oracle's SQL*Net driver for the Macintosh.

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Any user may create three different kinds of notebooks. These are:

Private Journals. Only the author (creator) of a private journal can read or write in it.
Group Project notebooks. A project notebook can have one or more authors. Only its authors are permitted to read or contribute to it.
Public Discussions. A discussion is a public notebook open for any member of the CoVis community to read and contribute to.

Within each notebook are an arbitrary number of pages, written by its authors. These can be organized in a variety of ways, from a simple sequential ordering (like that of Usenet newsgroups) to rather elaborate interconnected webs.

2.1 Writing in a Notebook

In order to help students organize and make sense of their efforts while working on science projects, the Collaboratory Notebook encourages them to write in small chunks, referred to as "pages". These pages are organized using hypermedia links that describe the relationships they bear to one another in a vocabulary of scientific dialogue.

When a notebook author or authors wish to write something new, they open a notebook, and create a new page within it. A "page writing window" then pops up on the screen, with blank areas for a page title and body text. There is also a button which provides a means of attaching pictures to the page.

Variations in Denver's December temps.
Variations in December temps
The only possible reason that we could think of for the variations in the graph is that this is natures way of controlling the tempertures on Earth. It is part of like the eco system everything balances out. The reason that the average temperature is rising in December is because humans are messing up the Earth. Our opinion is that if the earth were not populated by humans the average temperature would not rise at all it would just fluxuate. These are just our personal ideas about our question, we did not research any of what we have said in this paragraph.
This page is a conjecture
Cancel
Save

Figure 2. A new page being written by two authors.

The band of icons near the bottom of the page writing window provides authors with an array of possible labels to describe what they write. At any time in writing a page, the authors choose one of these labels. The software allows them to change their minds repeatedly in the course of their work, if their sense of what they have written changes; however, the computer does not save the page until some label has been chosen.

The set of page labels that we are presently experimenting with consists of:

- *information*
- a *commentary* on someone else's writing
- a *question*
- a *conjecture* (possible answer) for some question
- *evidence for* or *evidence against* a conjecture
- a *plan* for action
- a *step in a plan*

If a new page has been written in response to another page in the notebook, the software creates hypermedia links between the new page and the previous one, using the labels that their respective authors have given them. All of the choices of page labels are available to an author creating an entirely new page,

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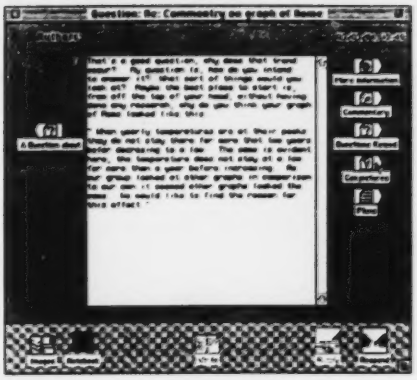

Figure 4. A notebook page being read

however an author writing a response to an older page is limited to a subset of these labels, according to the to the semantics of the label chosen for the page he is responding to. These limitations are put in place as a framework that encourages articulation of crucial steps in an inquiry.

For example, an author may not link a new page as evidence for or against a question, since a question does not put forward an explicit claim. However, an author may to respond to a question with a conjecture about a possible answer, and conjectures may in turn be responded to with evidence, since they imply predictions. In a similar fashion, a plan of action is not allowed as a response to the noncommittal "information", but is permitted as a response to a conjecture or a question, which more explicitly call out for investigation.

Page Type	Response Palette
Question	Information, Question, Commentary, Conjecture, Plan
Conjecture	Information, Question, Commentary, Plans, Evidence For, Evidence Against
Plan	Information, Question, Commentary, Step in a Plan

Figure 3. Response palettes available for question, conjecture and plan pages.

These varying sets of response palettes for pages of different types represent a kind of scaffolding for project-related dialogues. This dialogue scaffolding has embedded within it a simple research strategy: "begin with a question, project possible answers, develop a research plan, and follow each step through". In its gross structure and purpose, it bears some affinity to ideas such as Collins and Ferguson's (1993) "epistemic forms and epistemic games", and Perkins' (1986) "thinking frames"; though our emphasis here is more directly on facilitating a learning dialogue between collaborators than on an individuals' thinking.

2.2 Following Discussions in a Notebook

Notebook readers can follow threads of dialogue from page to page using link buttons that appear on the right and left of each page window (see Figure 4). The right-hand arrow buttons allow browsing forward in the web of dialogue, while the left-hand button allows browsing backward. The color of these buttons, which bear the names of the response categories for a page of the given type, change to indicate how many responses of each kind have been made to that page so far.

These colored link buttons serve two purposes. First, they show the "beaten paths" that others have taken in responding to each page, reflecting a kind of social consensus. Second, they serve as prompts for further writing. For instance, when a student reads a conjecture page, its display reminds him that in addition to raising questions about it, commenting, or adding more information, he might respond by providing evidence for or against it. Similarly, when he is reading a question, he is reminded that he could propose a conjecture about it or a plan to research an answer.

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A broader overview of the dialogue taking place in a notebook is provided by its table of contents (see Figure 5). This window shows the title and authorship of the notebook, and provides a scrolling list of its pages which can be sorted in several ways.

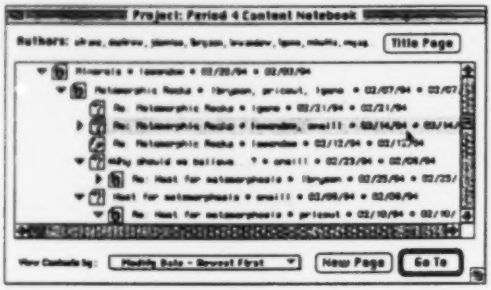

Figure 5. A notebook table of contents

Each line in the list of pages begins with an icon which indicates what type of page it represents. To the right of these are its title, a list of the authors who wrote it, and the date that they wrote it on. If a page has been responded to, it appears with a twist-down triangle to the left of it. Clicking on this triangle displays the immediate responses to that page, indented beneath it. More deeply indented pages are ones written further along in the chain of dialogue; thus, the table of contents for a notebook allows a reader to view, in diagrammatic form, any strand of conversation that has taken place within it. By clicking on any one of the pages, he can also jump directly to it without navigating from page to page.

3.0 Designers' Assumptions and Expectations of Use

Now that we have said a little about how the Collaboratory Notebook works, we would like to say something more about why we designed it as we did, and how we expected it to fit into its intended settings. At this point, we must outline a few of our theoretical perspectives on science learning. The most important of these are:

- The practice of science has important social dimensions which deserve a place in high school science learning. Learning about a science ideally involves a process of "enculturation" into a community of its practice, in the sense used by Perkins (1993).
- The process of enculturation into a community of practice includes the appropriation of some of the language which customarily accompanies and facilitates its tasks. Since language is acquired only through use (Bruner, 1990), students' articulation of their ideas and the process of their learning while they work is crucial to enculturation. (See Collins, in press, for further benefits of articulation.)
- The effort to reason purposefully in collaboration with others, especially in writing, provides the best possible motivation and occasion for articulation.
- Open and purposeful dialogue with respect to a shared goal is not, in itself, scientific. Rather, science has a unique speech genre of its own (Wertch, 1991), and science learning should provide students with experiences that will enable them to "find a voice" within it (Belenky et. al, 1986).
- Some elements of the scientific speech genre can be embodied within electronic media in such a way that they facilitate both the acts of investigation and the process of finding a voice within this speech genre.

In light of these theoretical perspectives, particular attention has been paid in the design of the Collaboratory Notebook to facilitating project-centered dialogue. This attention is reflected especially in two facets of the software.

Page Labels. We expected that our small, fixed set of page labels would have three significant advantages for the CoVis community. First, we wanted to draw students' attention to the small intermediate products that are required in the course of performing investigations. We believed this would be helpful to teachers and scientist mentors by providing significant milestones for them to use in tracking students' progress within a project.

Second, we expected that the conversations that students and teachers would have both within, and in reference to the Collaboratory Notebook would make explicit the privileged status given to questions, conjectures, research plans and evidence in scientific dialogue, and provide students with an opportunity to find a voice within this speech genre.

Last, we felt that a limited range of page types and possibilities for linking them would encourage the development of consistent conventions of use across the large, distributed community that CoVis supports. This, in turn, would facilitate remote collaboration and the fullest use of the intellectual resources of the community.

Tables of Contents. We anticipated that one of the teachers' and scientist mentors' greatest needs within the Collaboratory Notebook environment would be a means to rapidly determine the state of a project effort. In order to be effective coaches of project science, we felt that teachers and mentors would need to quickly determine where a project effort was headed, what had been accomplished, how labour was being distributed by the participants, and so on. By logging on and viewing the tables of contents for students' project notebooks, we expected that teachers and scientist mentors would be able to get a quick overview of what had been accomplished by a particular project team, without asking them to submit a report or make a formal presentation.

Besides the presence or absence of particular types of pages, a notebook's table of contents can indicate other things about a project effort that a coach might find useful to know. For example, if some group action, like a novel weather visualization, graphic, or illustration has been recorded, one may ask, was it followed up with research questions? Were these the sort of "wonderment" questions that seem likely to lead to new learning (Scardamalia and Bereiter, 1991), or merely the sort that one might answer by leafing through an encyclopedia? If wonderment questions were posed, were they followed up with any conjectures that could be proven or disproven with available or collectable data? And were plans made for collecting such data?

4.0 Lessons from Early Use of the Collaboratory Notebook

Though the software has only been available for use in our classrooms for five months at the time of this writing, some of our expectations about the purposes that it would serve have already been given significant testing. Four CoVis teachers have had their students use the software in a variety of project contexts, spanning roughly 45 hours of class time in total over the first three quarters of the 1993/1994 school year. In this time, 118 students in 6 classes have created 59 notebooks containing a total of 352 pages.

Our current design of page labels and links has met with mixed success. In at least two projects, this design seems to have helped teachers to make work assignments involving collaboration clear to their students. By sketching or modeling the hierarchies of notebook pages that they would like their students to create, teachers can describe in rough outline the kinds of dialogues that they see as suitable to a particular research purpose. This allows them to provide some high-level guidance to their students with respect to dialogues between student collaborators, and among student collaborators and remote mentors.

Our expectation that a small set of page types would help in establishing conventions for the use of Collaboratory Notebook seems to have been partially validated as well. In classroom uses so far, we have seen customs of work arise that involve specific forms of page hierarchies to support dialogues for a variety of ends. For example, teachers have invented forms to support the revision of successive drafts of students' project proposals, the organization of knowledge gleaned by students from interviews with experts, the pooling of knowledge about weather prediction, and the sharing of responsibility between a teacher and a graduate student for mentoring groups of students working on projects.

To this point, however, the range of page labels in our experimental set has not been used to its fullest. Although students and teachers took very easily to using the information, question, commentary and plan labels to compose simple webs of project-centered dialogue, it is taking some time for them to develop more elaborate customs that involve conjecture and evidence pages in a way that is central to these conversations. This, we believe, is a reflection of many things: of (1) the fact that both our teachers and students are new to the project-enhanced method of science learning, (2) the need for new assessment strategies to complement the new modes of learning, (3) the practical limitations of our software and the technical setting in which it is used, and (4) our own difficulty in communicating the purposes and potential uses of the software clearly to teachers at an early stage. We will attempt to explain each of these now in turn.

Though the ultimate goal of building CoVis' distributed learning environment is to make the teaching and learning practices of high school more similar to those of the research lab, classroom practices in a public school science classroom arise from a marriage between this tradition and its own, very different

one. Part of the difficulty that our teachers and students are facing in their adoption of the Collaboratory Notebook seems to stem from the sharp disjunction between the inquiry-centered dialogue that is privileged by our software's page labels, and the assessment-driven dialogues that traditionally take place in classrooms. On the whole, our teachers have been loath to assign any work to which they cannot confidently attach a grade value, and their students have been quite opposed to doing such work. Since our teachers are only just beginning to adopt the kinds of metrics that will help them to assess the work done by their students' using the Collaboratory Notebook, their efforts to make better use of the tool are likely to move in step with this initiative.

In light of the strong bond between assessment and adoption, it may be useful for us to alter our design to incorporate special forms of pages for project proposals, delivery contracts between teachers and students, and even interim status reports from teachers. In appropriating the software to their current uses, teachers and students have frequently used our "information" pages for purposes like these.

Our tables of contents proved to be a good start for a project monitoring and assessment aid, but will clearly not be adequate to this purpose in the long run. It has proven more time- and labor-intensive than we had anticipated for teachers to track student progress on projects, primarily because a notebook's table of contents does not provide them with a simple and efficient way to track change from day to day or week to week. Before the start of the next school year, we plan to implement a set of tools designed specifically to aid in project monitoring. These will need to be designed in close consultation with teachers.

In the future, we will also need to be more concerned to provide our teachers with ways to review their students' work at home, as they are accustomed to doing with paper documents. Since our software currently makes large demands on both system RAM and the speed of its connection to our database server, our teachers are not all currently equipped to use the software from their homes using the university SLIP facilities. As a partial solution to this problem, we recently implemented a new software feature that allows teachers to download a notebook's entire contents to a floppy disk, and read it at home with a standalone version of the application. However, this does not provide help to teachers who do not have computers capable of running our software.

5.0 Challenges for the Design and use of Groupware for School Settings

In addition to those stated above, three more general lessons that the CoVis team has learned this year deserve special attention by developers and users of future systems to support collaborative learning over distance.

First, in order to reap the pedagogical benefit of technologies for asynchronous collaboration, one must take care only to apply them in projects for which collaboration is needed. The coordination of multi-party efforts over time must be integral to students' efforts in producing the results desired for a project, or the challenge of the collaboration itself will only serve as an annoyance. In our experience, collaboration is not considered a benefit by high school students unless it is directly useful to completing the work that is assigned them. Thus, if one attempts to add an element of collaboration to students' traditional work in an effort to make it more motivating, the results are very likely to disappoint.

Second, the network connections and servers that support a distributed, multimedia learning environment like that of CoVis must be very well maintained and *very* reliable. Because class periods are usually quite short, even a five minute interruption in service at an inopportune moment can throw teachers' and students' plans into an unrecoverable tailspin; and a loose ethernet connector in the wrong place can degrade the performance of an application like the Collaboratory Notebook significantly. If network resources are relied upon to a degree that will justify their cost, such failures can generate significant distrust and disuse of the technology—even among the most technically savvy teachers and students.

Finally, since teachers often plan the gross structure of their curricula far in advance, it is extremely important for developers to communicate the purpose and promise of groupware tools as early on as possible, in a way that teachers can clearly relate to their own curricular goals and classroom practices. In an environment like the CoVis testbed, where teachers and students have access to a large variety of electronic media including email and netnews, fitting a tool to a purpose can be difficult. For this reason, the special uses of the different tools need to be clearly set out, and consultants must be available with whom teachers can discuss and develop their plans to use them.

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